Chapter 5. CUMULATIVE EFFECTS

The current status of herring stocks in California was discussed in Chapter 3. A variety of factors have the capacity to influence future Pacific herring population status in California in addition to the proposed project or alternatives. The factors with the greatest potential include continued commercial harvest of herring, unusual biological events, competitive interactions with other pelagic fish, unusual weather events, habitat loss, and water quality. Several of these factors have been discussed [Sec 3.2], but will be reviewed briefly.

5.1 Continued Commercial Harvest of Herring

Although the proposed project only provides for the regulated commercial harvest of Pacific herring during the 1998-99 season, the long-term impacts from continued harvest should be considered [Sec 4.2.1.6]. A computer model was used to test the long-term impacts of various harvest strategies [Sec 3.2.4]. The harvest strategy selected for use in California was considered to be conservative and did not lead to herring population declines during a 100-year simulation. The policies guiding the management of the state's herring resource, annual herring stock assessments, and the regulations designed to achieve the management objectives, are reviewed annually to insure the continued viability of a herring resource [Sec 3.2.4]. Changes are made to the regulatory framework as necessary based on this review and their utility assessed in subsequent reviews. The process, then, is dynamic and should reduce the likelihood of long-term deleterious impacts associated with the ongoing commercial harvest of Pacific herring to less-than-significant levels. Any long-term deleterious impacts would become apparent over a protracted period, not in the course of a single season.

5.2 Unusual Biological Events

The level of natural mortality assumed in the PFMC model [Appendix 3] (M = 0.4) to assess various harvest strategies may not be high enough to account for several potential changes in marine community structure. If the actual natural mortality rate is appreciably higher than assumed, the model will not accurately predict the impact of the selected harvest strategy. Additionally, the model assumes constant recruitment, and does not account for successive years of poor recruitment. If the factors influencing recruitment cause several contiguous years of poor recruitment, the model will not accurately predict the impact of the selected harvest strategy.

As with most marine fishes, no direct measure of the actual rate of natural mortality for herring is available. Any trend in predation could influence those rates without being recognized in the short-term. For example, a trend of increased predation would result in an increase in the rate of natural mortality, thus influencing the predictive capability of the PFMC model. Marine mammals are completely protected and a number of marine mammal populations are growing. A study of harbor seal food habits in the Monterey Bay area documented an increase in predation on herring associated with increases in harbor seal population size and shifts in foraging areas (Suryan and Raum-Suryan 1990). The potential exists, then, for an increase in the rate of predation by marine mammals and an increase in natural mortality for herring. This would require lower fishing harvest levels than currently used.

Several foreseeable changes in the marine community of which herring are a part could increase the possibility of poor recruitment during contiguous years. One such change with the potential for negatively impacting herring recruitment is the invasion and population explosion of the

Asian clam in San Francisco Bay (Carlton et al. 1990, Nichols et al. 1990). This clam has demonstrated a remarkable capacity to reduce the standing crop of phytoplankton and zooplankton within the Bay. One of the critical stages in herring life history [Sec 3.2.1.4] is the age at first feeding. Success at this stage can lead to good year class recruitment. If the availability of herring prey (phytoplankton and microzooplankton) is chronically reduced, natural mortality of prerecruit ages could become chronically higher than previously experienced. As noted, the PFMC model used to predict appropriate harvest levels does not account for poor recruitment.

5.3 Competitive Interactions with Other Pelagic Fish

Herring are one of many small pelagic schooling fish to occupy the nearshore waters off the California coast. Interspecific links (e.g. competition at the larval, juvenile or adult stage), differential effects of fishing, or changes in the environment may preferentially favor one over the other of these species, leading to large shifts in their relative abundance. The large changes in the relative abundance of the anchovy and sardine in California, based on a study of fish scales in sediments collected in anaerobic basins, is an example of this type of shift (Soutar and Isaacs 1974).

5.4 Oceanographic Events

The occurrence of oceanographic conditions such as the El Niño phenomenon (warming of the ocean due to unusual changes in current systems) has had significant influences on the relative abundance of small pelagic schooling fishes. The present El Niño is one of the strongest on record, and heavily impacted herring stocks. The San Francisco Bay spawning population declined 78%. Many of the fish that did return to spawn showed signs of poor condition, such as low body weight and abnormal egg skeins. Given the large spawning biomass estimated for San Francisco Bay for the 1996-97 and 1995-96 seasons, and the strength of the 1995, 1994, 1993 and 1992 year-classes, many fewer herring than expected returned to spawn in San Francisco Bay for the 1997-98 season. Whether poor ocean conditions caused by El Niño increased natural mortality or prevented herring from reaching reproductive condition remains to be seen. The last acute El Niño to severely affect California herring occurred in 1983. During this El Niño, the San Francisco Bay herring spawning biomass declined 60 percent, and growth rates and condition factors of herring were also poor (Spratt 1987). Less acute but longer-lasting warm water conditions occurred during 1986-87 and the early 1990's. Nutrient-depleted warm water masses and reduced prey availability that are associated with El Niños are expected to be detrimental to California's herring stocks. El Niños have had significant influences (including contributing to stock collapse) on other pelagic schooling species in other areas (Lasker 1985, Glantz and Thompson 1981).

In addition to warmer water and associated low productivity, El Niño events are often characterized by increased rainfall, resulting in lower salinities in bays and estuaries. While increased freshwater is thought to act as a trigger for spawning, too much freshwater can decrease embryo survival (Cherr and Pillai 1994).

5.5 Habitat Loss

The loss or degradation of spawning habitat can have an impact on the spawning success of herring. Loss of habitat has affected the status of other fish populations such as the endangered Sacramento river winter-run king salmon (PFMC 1990).

Herring use both hard substrate and vegetation as a spawning substrate [Sec 3.2.1.3]. Pier

pilings are a frequently-used substrate in San Francisco Bay. However, it is likely that pilings treated with anti-fouling agents (e.g. creosote) are toxic to herring embryos and represent a source of mortality. The 1996 Cape Mohican Oil Spill along the San Francisco waterfront deposited oil on pier pilings within a six foot tidal amplitude zone prior to the 1996-97 spawning season. Potential exists for this oil to also cause mortality of herring embryos spawned on pier pilings.

No significant changes are expected in the quantity of man-made hard substrate (e.g. pier pilings) in the foreseeable future. The San Francisco Bay Conservation and Development Commission (BCDC) regulates development within the first 100 feet inland from the Bay, as well as all filling and dredging. During the 19-year period ending in 1988 there was only a net increase in Bay surface area of 760 acres (BCDC 1988). However, the abundance and distribution of vegetation suitable for spawning has changed and could change to greater extents in the foreseeable future.

Eelgrass is an important and often critical component of the nearshore ecosystem. Eelgrass is commonly found in relatively calm estuarine environments and is vulnerable to coastal urbanization that heavily targets these same environments. Efforts to mitigate the effects of development have generally been inadequate. Light, temperature, salinity, tidal range, and water motion influence growth and productivity of eelgrass. However, light most often appears to be the controlling factor. Processes that increase the overall turbidity of the estuarine environment could have marked effects on eelgrass density and distribution (Zimmerman et al. 1991). Long-term reduction in the availability of suitable spawning substrate such as eelgrass would increase the vulnerability of herring to perturbations.

The red algae, *Gracilaria* spp., was abundant and commonly used by herring in San Francisco Bay as a spawning substrate during the 1970s and early 1980s (Spratt 1981). Richardson Bay, with its dense *Gracilaria* beds, was the primary subtidal spawning area in the Bay during this time. With the decline in *Gracilaria* densities (0.48 kg/m² to 0.04 kg/m²) in 1982, Richardson Bay was relegated to a minor spawning area (Spratt 1983). Storm action during the 1982-83 El Niño is thought to have removed much of the *Gracilaria* sp. from the area. The trend of herring spawning in areas of San Francisco Bay other than Richardson Bay continued through the 1992-93 season. *Gracilaria* sp. densities increased to a mean of 0.39 kg/m² for the 1993-94 season. In addition, eelgrass has expanded in abundance in Richardson Bay in recent years. Perhaps as a consequence, spawning activity has increased in Richardson Bay in recent seasons. Since the 1995-96 season, *Gracilaria* sp. has been difficult to find in Richardson Bay, while eelgrass distribution has increased slightly. The reason for the disappearance of *Gracilaria* sp. in this area is not known. Despite the loss of subtidal vegetation, Pacific herring have continued to spawn in Richardson Bay, often on pilings and boat bottoms in marinas as well as on eelgrass.

5.6 Water Quality

San Francisco Bay, like other urbanized estuaries, faces continuing water quality problems. Contributing to the problem are the multiplicity of pollution sources, limited water exchange capabilities, and reduced volume of fresh water inflow. The quantity of hazardous wastes generated in the Bay region is expected to increase (BCDC 1988). These pollutants, acting singly or in combination, could influence the viability of herring using the Bay. For example, a large spill of elemental phosphorus caused high mortality in a Canadian herring population (Jangaard 1972).

Although overall chemical and physical conditions such as turbidity, nutrients, coliform

organisms and chemical oxygen demand in the Bay have been improved, pollutants still exist in the water column, sediments, and tissue in concentrations which are cause for concern (SWRCB 1989). Pollutants of particular concern because of the aquatic toxicity to biota include heavy metals (cadmium, chromium, copper, mercury, selenium, silver, tributyltin), hydrocarbons, and agricultural chemicals (chlorinated hydrocarbons and organo-phosphates). These substances are not readily transported from the system nor are they readily broken down since the physical, chemical, and biological processes affecting them are slow.

Dredging is an ongoing loading source that can make formerly isolated contaminants available, and several of these pollutants are known to bioaccumulate (SWRCB 1989). Dredging and disposal of dredge spoils within the Bay contribute to elevated levels of turbidity as well. Particular concern exists over the presence of radiation and other contaminants in the sediments at the Treasure Island Naval Station Hunters Point Annex (Barbara Smith, Regional Water Quality Control Board, pers. comm., Jeff Lewis, Department of the Navy, pers. comm.). Herring utilize pier pilings, sea walls, and rocky shoreline at Hunters Point for spawning. It is not known what effect, if any, contaminated sediments have on egg and larval survival. A restricted zone prohibits vessel traffic in the vicinity of Hunters Point. Illegal fishing activity in the Hunters Point area would disturb sediments and possibly create an increased yet short-term exposure hazard to humans as well as the biota (Agency for Toxic Substances and Disease Registry, 1994).

Although the direct and indirect effects of these pollutants on various life stages of herring are largely unknown, their toxic effect on marine organisms has been well documented (SWRCB 1989). The likelihood of increased loading of many pollutants could have impacts on the herring resource in San Francisco Bay.

Increased fresh water inflow occurs periodically during increased rainfall years, often associated with El Niño conditions. During the 1996-97 season, a series of warm, tropical storms dramatically decreased salinities in San Francisco and Tomales Bays. Spawning was delayed by as much as three weeks during January, and the survival of embryos was probably affected. Reduced fresh water inflows, either from drought or diversion, have had significant impacts on estuarian benthic community structure (Carlton et al. 1990, Herrgesell 1983). The Department's Bay/Delta Project has gathered data that suggests an association between young-of-the-year herring abundance and high Delta outflows (Kathy Hieb, Bay/Delta Project, pers. comm.). Although spawning, fertilization, hatching and larval development occur under a wide range of reduced salinities, studies have established optimal salinities for herring spawning and young-ofthe-year survival. For example, for British Columbia herring stocks, Alderdice and Hourston (1985) reported optimal salinities for spawning (27-28.7ppt) and hatching (17.0 ppt); Alderdice and Velsen (1971) reported optimal salinity of 16.4 ppt for larval development. For San Francisco Bay herring, Griffin et al. (1998) reported optimal salinity for fertilization at 12-24 ppt, and optimal salinity for development through hatching at 8-24 ppt. Fertilization was inhibited at high (28 ppt, 32 ppt) and low (4 ppt, 8 ppt) salinities (Griffin et al. 1998). Several studies have shown that higher salinities are tolerable for herring reproduction if temperatures are low. Therefore, it is possible that the combination of increased salinities in the Bay (due to reduced Delta outflows during the recent seven-year drought) with a prolonged warm water period contributed to the decline of San Francisco Bay's herring population in the early 1990's. Reduced fresh water inflows have also been identified as a potential factor affecting the use of Tomales Bay as a herring spawning area (Spratt 1990). Fresh water inflow into San Francisco Bay has been influenced by water development activities.

Inflows have been reduced by construction of upstream reservoirs, increased consumptive uses in the basin, and exports. Existing developments have reduced inflow levels for most months during all water-year types. However, the proportional reductions are more severe during dry and critical years than in wet or normal years.

The combined influence of drought and water diversion on salinity profiles within San Francisco Bay will result in salt water intrusion further into the estuary. However, assessing the impact of these changes on herring use of the Bay is difficult and conjectural.

If San Francisco Bay remains an acceptable spawning area for herring, drought and diversion-related changes in the salinity profile in various reaches of the Bay could result in more spawning area in San Pablo Bay. Herring have used the highly marine reaches of the Bay as spawning areas. Decreasing fresh water inflow could change San Pablo Bay to a more marine-influenced reach. The point of concern is whether decreased salinities are necessary in the selection and timing of use of any or all of an estuary as a spawning area. Decreased fresh water inflows could simply cause a shift in spawning areas.

Mitigation: Several potential cumulative impacts have been identified that could result in unusual stress being placed on the commercially harvested herring resources. In the foreseeable future these impacts are less than significant. Regardless of the level of impact from cumulative effects, mitigation will be provided through changes in the level of commercial harvest of herring or in selection of a no fishery alternative. These changes will occur through the annual review process and subsequent adjustments to commercial herring regulations.